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## Paper Session I-C - Maximizing World Benefits from Space Endeavors

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## **MAXIMIZING WORLD BENEFITS FROM SPACE ENDEAVORS**

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Canaveral Council of Technical Societies  
Thirtieth Space Congress  
Cocoa Beach, Florida  
27-30 April 1993

*McDonnell Douglas Aerospace*  
*Space Systems*

**MCDONNELL DOUGLAS**

## MAXIMIZING WORLD BENEFITS FROM SPACE ENDEAVORS

### Abstract

United States and world space programs have been the reagent for many real and perceived benefits to the American economy and the world in general. While many space programs were derived without a synergistic process, future space endeavors can provide opportunities to pursue technologies that could benefit the world in many ways. Goals can be set and development pursued through synergistic action and collective goals that lead to low cost, nonpolluting power systems, low water and low pesticide plant growth techniques, improved waste and water control systems, and, perhaps, solutions to problems such as osteoporosis and diseases caused by failure of the human immune system. Space exploration can be a catalyst for a better world while meeting both national and international goals.

This paper not only analyzes benefits to the U.S. economy, education, and industrial leadership, but also recommends that future national or international space endeavors emphasize a new beginning. Development dollars for new space exploration systems can be focused in part on world needs by utilizing technologies most likely to benefit the economy and aid in creating potential solutions to existing and future world problems. Space exploration can generate benefits of far greater value than its overall cost.

### Introduction

Ten years ago, American workers earned higher wages than those in any other country. Now we're ranked 13th and falling. Our competitors are growing and earning more because they educate their people better, invest more in the future, and organize their economies to compete. The sad truth is that we have 1.4 million fewer manufacturing jobs now than we did four years ago. A recent study by the Council on Competitiveness identified the state of our industrial stewardship as shown in Table 1. It is not a good picture.

Table 1. Technology leadership Council on Competitiveness report

|   |  |
|---|--|
| Reviewed 94 technologies critical during 1990's | <ul style="list-style-type: none"><li>■ In 60 areas, U.S. is a world leader or competitive</li><li>■ In 34 areas, we are no longer a factor</li></ul>  |
| Major technology deficiencies found             | <ul style="list-style-type: none"><li>■ Silicon production</li><li>■ Factory robotic automation</li><li>■ Machine tools</li><li>■ Display materials</li><li>■ Computer memory chips</li><li>■ Semiconductors</li></ul> |
| Weak or losing in                               | <ul style="list-style-type: none"><li>■ 12 electronic components</li><li>■ 11 engineering and production technologies</li></ul>  |

H1306, Table 1, 1/28/93, 04:31 PM

Our last surviving industrial "crown jewel" is the American aerospace industry. As a source of technological innovation, it has far-reaching implications for every sector of the American economy. Indeed, it holds one of the keys to future prosperity. Vice President Al Gore, in a 19

October 1992 speech, said that government should focus its efforts on preserving our aerospace industries.

From 1980 to 1985, industrial research and development (R&D) in the U.S. was growing at an average annual rate of 7.5%. From 1986 to 1990, the growth rate was almost zero. Federal support for civilian R&D declined by a similar amount. With the demise of the Cold War, budget cutters facing record deficits now look at NASA's budget like a barn full of seed corn. Will we plant it or eat it? The technology generated from the space program is one of the highest yielding investments in our future economic growth this country can make. Every dollar spent on civilian space programs generates about seven dollars worth of economic activity. According to NASA Administrator D.S. Goldin in a 24 August 1992 speech, many new products, industries, and jobs are the result of NASA research.

Many space programs were not derived through a synergistic process. With proper planning, we can utilize space endeavors to further world peace, push technology development for world benefit, and help stabilize the aerospace industry while engendering future commercial competitiveness.

In the early 1980s, McDonnell Douglas and Eagle Engineering studied the potential benefits of space exploration activities. Their study suggested an approach to space architecture that could help maximize world benefits while pursuing cost-effective space exploitation and exploration. This paper briefly summarizes their analysis.

### The Premise

Following President Bush's 20 July 1989 space challenge, we all busily analyzed the "how" of future space activity rather than the "why". We have generated scenarios based on achieving a perceived goal within cost and schedule guidelines. As previously, we reached our goals and then told the public, the ultimate paymaster, that it was good for them. We extol transistor radios and weather satellites, attempt to conduct benefit analysis after the fact, and then imply great future benefits of unknown nature from the next program. This approach has failed to capture adequate support from both the public and Congress. We have a great task before us. How do we change both public and legislative opinions, and how might we structure the program to gain national support?

As in all problems requiring a solution, the most difficult, and sometimes preeminent task, is that of properly posing the question. A global problem requires precise structure to limit the discussion and direct our thoughts. Table 2 accomplishes this. This set of questions will be utilized to structure the remainder of the presentation. First it deals with general civil space benefits to the United States. Secondly, it proposes an approach to space exploration that might maximize the possible benefits to not only the nation, but also the world.

Table 2. Posing the first-order question

|   |   |
|---|---|
| To solve many difficult problems, the most important task is to properly pose the question. | <ul style="list-style-type: none"> <li>How do you evaluate the economic feedback of technology?</li> <li>What have been the major feedbacks (spinoffs) into the economy in the past?</li> <li>How many dollars are invested annually in R&amp;D by the U.S.?</li> <li>How does a given program influence the educational system, particularly higher education?</li> <li>What other ways does a NASA program influence the folks back home?</li> <li>Who are the interested players?</li> <li>How can the SEI scenario be structured to maximize technology?</li> </ul> |
|---|---|

H1306, Table 2, 1/28/93, 04:31 PM

## The U.S. Economy

For our purposes, we define the U.S. economy in terms of the U.S. trade balance, export-import data, per-capita income, and the consumer price index.

In recent years, the U.S. trade deficit has reached its highest figure ever. Aerospace and agriculture are the only significant U.S. industries with trade surpluses. Recent events, such as the sale of advanced fighter technology to Japan and competition in the commercial space launch market, will no doubt reduce world dependence on U.S. aerospace technology and further reduce exports. Figure 1 shows a partial breakdown of the trade imbalance between the Western space powers. The dollar figures indicated by the arrows represent the annual dollar value of trade between the respective countries.

The U.S. imbalance is primarily with Japan, but we run trade deficits with all the economic powers shown. The data shown are for 1989, a period well before the European economic realignment in 1992. We have lost the lead in electronics, machinery, manufactured goods, and automobile exports. However, a concerted effort in space and possibly agriculture research by the universities and U.S. industry will maintain our dominance in aerospace and agriculture. By creating new technologies for manufacturing, promoting more competitive products, and helping to close the electronics gap by recovering our lead in high technology electronics, our dwindling lead can be reversed.

When compared to Europe and Japan, U.S. per capita income is improving due to falling unemployment (a trend reversed in the first quarter of fiscal year (FY) 91 and subsequently) and inflation rates. Japan still has the highest per capita income with Italy and Great Britain bringing up the rear. As our employment level declines, the space program remains one of the few hopes to reverse the unemployment trend. This leverage will be discussed later. The consumer price index (a comparison of the average change in prices over time in a fixed market) in the U.S. and Europe has been relatively stable at -6% over the last few years, but Japan is gaining from its decreasing levels of 1987. Significantly, most countries have similar trends; we are approaching a global economy.

Now the trends of Table 3 appear and must be reversed. The space program remains one of the few major industries that could change our ever-decreasing economic trend and its effect on the aerospace industry.

Table 3. Conclusions regarding the U.S. economy

- The U.S. has overall trade deficits with every major participant of international trade
- Exports of aerospace and agricultural commodities account for the only significant accumulations in U.S. trade
- The U.S. spends approximately \$2 for every \$1 it sells in trade with Japan
- Per capita income was on the rise in the U.S. due to 1990 inflation and unemployment declines, but this trend was short-lived
- Changes in the consumer price index for all economic powers indicate the global nature of the economy

H1306, Table 3, 1/28/93, 4:31 PM

## The U.S. Economy and Civil Space

Here we will show the relationship of civil space to the U.S. economy, the R&D planned in FY 1991, and past spin-offs realized from space expenditures. The general effect of civil space on the U.S. economy is summarized in Table 4.

Over and above the direct benefits received by the states having a major aerospace industry, there are indirect benefits in all states. Ranging from 4-to-1 ratios in the major states benefited, to as high as a 10-to-1 ratio in states such as Kentucky, Oklahoma, Indiana, and Michigan, states not normally considered as aerospace industry players are receiving significant benefits. A summary of civil space job

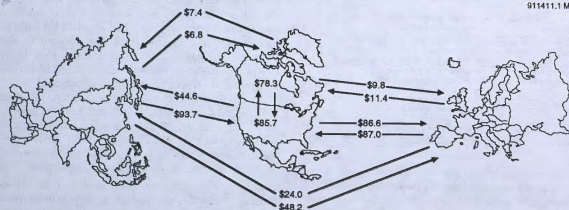


Figure 1. Trade balances in billions of 1989 U.S. dollars

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**Table 4. How does the U.S. economy relate to civil space**

|   |  |
|---|--|
| ■ Method of measurement   | <ul style="list-style-type: none"> <li>■ Direct: Those states awarded NASA procurement dollars</li> <li>■ Indirect: Those states producing goods and services required by recipients of NASA procurement awards</li> <li>■ Number of jobs created: White and blue collar</li> </ul>                          |
| ■ Highlights of FY90 \$12.3 billion procurement expenditures created, directly and indirectly   | <ul style="list-style-type: none"> <li>■ 237,000 jobs in private industry</li> <li>■ \$23.2 billion in total industry sales</li> <li>■ \$500 million in corporate-funded R&amp;D</li> <li>■ \$2.4 billion in corporate profits</li> <li>■ \$7.4 billion in federal, state, and local tax revenues</li> </ul> |
| ■ States benefiting most from U.S. space program are those with large aerospace industries, but other states also benefit significantly |  |
| ■ Many industries other than aerospace benefit from NASA procurement as indicated by high economic multipliers                          |  |

H1306, Table 4, 1/28/93, 04:31 PM

creation and distribution in the national economy is shown in Table 5.

**Table 5. Job creation and distribution resulting from civil space**

|  |
|--|
| <ul style="list-style-type: none"> <li>■ Approximately 17% of jobs are created within engineering science, and skilled labor field</li> <li>■ Many jobs created are for blue collar and lesser skilled labor not normally linked to space program</li> <li>■ Every state in the U.S. receives economic and employment benefits from NASA procurements</li> <li>■ States directly benefiting have economic ratio as high as 14.0 to 1</li> <li>■ Indirect benefits to states also have economic multipliers of significant value</li> </ul> |
|--|

H1306, Table 5, 1/28/93, 04:31 PM

## Past Spin-Offs

A summary of spin-offs and feedbacks from past civil space programs is shown in Table 6. These data are further augmented by information shown in Table 7, which contains an estimate of the dollar value (in millions) of technological pull-throughs subdivided by end use. The data were generated by the Chapman Research Group for the 1978 to 1986 time period. These data are derived from space programs that were not specifically structured to produce other product benefits.

**Table 6. What were past spin-offs and feedbacks from civil space**

|   |  |
|---|--|
| <ul style="list-style-type: none"> <li>■ Over 32,000 spin-offs, NASA does not accurately track dollar value</li> <li>■ Most important spin-off – U.S. aerospace industry still No. 1</li> <li>■ Second most important spin-off – technical and practical knowledge of what can and should be done in space – how space and earth relate</li> <li>■ Fourth – specific hardware and software</li> </ul> | <ul style="list-style-type: none"> <li>■ Cannot identify most important</li> <li>■ Estimated dollar value: \$10 to \$100 billion</li> <li>■ One of few U.S. industries with close government and industry cooperation in R&amp;D</li> <li>■ DOD and DOE are major parts of it all</li> <li>■ Difficult to point to one factor – perhaps total NASA/DOD/DOE budget</li> <li>■ Almost all small items, individual dollar values are not large</li> <li>■ NASA tracks and documents many through Technical Utilization and Patent Office</li> </ul> |
|---|--|

H1306, Table 6, 1/28/93, 04:31 PM

**Table 7. Dollar value of technical pull-throughs (in millions)**

| End use description               | No. of cases | Cases with sales savings | Sales               | Benefits savings | Realized total      |
|-----------------------------------|--------------|--------------------------|---------------------|------------------|---------------------|
| Communication and Data Processing | 51           | 32                       | 171,007             | 51,964           | 222,971             |
| Energy                            | 30           | 13                       | 203,500             | 15,613           | 219,113             |
| Industrial (mfg and processing)   | 170          | 107                      | 5,767,649           | 67,837           | 5,835,486           |
| Medical                           | 61           | 31                       | 2,003,036           | 30,613           | 2,033,649           |
| Consumer products                 | 24           | 18                       | 1,278,294           | 524              | 1,278,818           |
| Public safety                     | 27           | 16                       | 347,888             | 555              | 348,443             |
| Transportation                    | 40           | 18                       | 9,887,865           | 116,623          | 10,004,488          |
| Environmental                     | 16           | 11                       | 16,962              | 21,788           | 38,750              |
| Other                             | 22           | 13                       | 1,654,989           | 10,232           | 1,665,221           |
| <b>Total</b>                      | <b>441</b>   | <b>259</b>               | <b>\$21,331,190</b> | <b>\$315,749</b> | <b>\$21,646,939</b> |

H1306, Table 7, 1/28/93, 04:31 PM

This analysis does not address the overall feedback of increased competitiveness into the aerospace industry as a whole. Many foreign companies are now teaming in pursuit of civil space government and commercial endeavors as are foreign nations. Somehow the public only sees the amount of money spent. The aerospace community must help publicize spin-offs in the microelectronics, medical, life sciences, software, materials research, and other fields that best feed back into the civilian economy as commercial applications. Table 8 shows examples of potential critical technologies with commercial value according to the National Aeronautics and Space Administration (NASA) Science Technology Council (NSTC).

## Higher Education

The education problem in the United States has been analyzed many times. Rising illiteracy and the 50% of foreign doctorates who return to their country of origin after their U.S. education is startling. In a recent Chinese space program personnel description, over 95% of those whose biographies were given were educated in the U.S. U.S. science and engineering schools are recognized throughout the world for excellence, but the number and percentage of U.S. students in attendance is declining. If the U.S. desires to maintain its leadership role in space and be competitive in industry, it must encourage young students to select engineering and high technology fields for study. During the Apollo program, as NASA spending increased so too did the number of doctorates received (Figure 2).

When NASA spending decreased following the Apollo program, so too did the number of doctorates received a few years later. This time lag occurred since many students were well on their way to achieving high-level degrees when NASA cutbacks began. Once it was clear that NASA funding was decreasing along with federal support for students, the number of students pursuing doctorates in these fields plummeted. The Apollo program had two direct effects on the Ph.D. population. First, the lag seen between the peaks of degrees conferred and NASA spending cuts caused a surplus of highly trained people

Table 8. NSTC-critical technologies with commercial applications

| Area  | Technology elements  |
|---|--|
| Adaptive automation   | Artificial intelligence, expert systems, neural networks, nonlinear dynamics and control, sensing and perception, human factors (man and machine interface), knowledge representation and acquisition, fuzzy logic networks                                  |
| Information acquisition, processing, display                                  | Sensor systems, neural networks, artificial intelligence, expert systems, advanced displays, virtual displays, advanced computer systems, algorithm development, superconductivity devices   |
| Transportation  | Computational methods (fluids and solid mechanics, integrated design), aeronautics and space propulsion systems, high-strength and density airframe and engine structural materials, adaptive vehicle and system control and operations, composite structure |
| Materials   | Materials and processing: metals, ceramics, organics, composites; manufacturing technologies: processing, automation, quality control  |
| Optical communication and photons   | Free space optical communications, optoelectronics, optical computer and processors  |
| Nano-technology and nano-electronics  | Semiconductor patterning and etching, nano-sensors, quantum wave effects on electronic performance   |
| Energy generation and photovoltaic energy conversion electro-chemical systems | Batteries and fuel cells, power management, Stirling power conversion, space environmental effects, electrophysics, solar concentration, heat receivers and radiation  |
| NSTC NASA Science Technology Council  |  |

H1306, Table 8, 1/26/93, 04:31 PM

Table 9. Conclusions regarding the higher education connection

- Long-term government commitment to space exploration is the key to attracting young people to high technology careers
- Students entering engineering fields have dropped in numbers and high attrition rates are leading to industry-wide shortages of engineers of all disciplines
- The Apollo program established the relationship between space exploration and education as enrollment increased and decreased along with program funding and support
- Space exploration must have near- and long-term goals to attract young people now to make a commitment to their future education and career

H1306, Table 9, 1/26/93, 04:31 PM

United States corporations can play a vital role in revitalizing the U.S. educational system through sharing the excitement of exploration with the young people of today. McDonnell Douglas has entered into this arena by taking part in a program called "Visions of Exploration: Past, Present, Future" with the USA Today newspaper and NASA. The program provides news to children in the classroom through current editions of USA Today. Utilizing today's news, teachers are provided with weekly lesson plans and a curriculum guide to illustrate the theme of exploration from Columbus' journey to a manned Mars expedition. We hope this exciting program will stimulate a renewed interest in science and math careers that the U.S. will need for the 21st century. The pilot program is currently in place in four school districts across the country including Orange County, Florida; Houston, Texas; Cleveland, Ohio; and Los Angeles, California. Forty-eight classrooms per district with grade levels 3 through 8 are participating. The pilot program is 10 weeks in duration. Participating teachers will comment on the curriculum guide and the effectiveness of space exploration in capturing children's interest. Feedback from the children and teachers, along with the role of industry in education, will be analyzed and presented in a formal report.

#### Civil Space Participants

As we discussed earlier, NASA contracts exist in all 50 states. Future space R&D programs will utilize both Department of Energy (DOE) and Department of Defense (DOD) laboratories and many universities, and most likely will be international. Even though space, science, commerce, and transportation committees are represented by aerospace-dominant states with more emphasis in the House than the Senate, the Civil Space budget is not widely supported. The percentage increase given in FY91 was more than any other federal spending area, but general support for civil space is still poor. Too much of the public and Congress do not perceive the benefits of civil space; we must inform them. The recent cold war cessation has had many effects. In addition to the clamor call for reduction in defense spending, there has been a concomitant reduction in aerospace employment. Industry has been forced to reduce capacity to remain competitive. We have also begun to seek new, innovative ways to maintain our technological skills, and this is positive. In the future, reduced capacity will endanger our aerospace competitiveness as our knowledge base declines, since the same fundamental engineering and related technical skills are used in both space, missiles, aircraft, and commercial

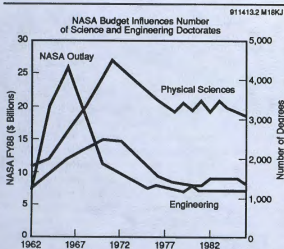


Figure 2. Space exploration will encourage a new generation of scientists and engineers

creating unemployment. Second, many prospective students sought other careers due to the lack of commitment by the government for space activities thus leading to the engineering shortfalls seen today.

A few conclusions can be reached about the higher education connection as shown in Table 9. A long-term continuous government commitment must be made to space exploration. This will attract young people to make an educational commitment to their future. We must convince the present elementary school students to commit to science and engineering; they are the key to our future.

ventures. McDonnell Douglas alone has reduced its work force by 30% (26,000 fewer employed) since 1990 with future reductions planned due to deeper defense budget cuts. Most major aerospace companies are forming world alliances to remain competitive, and many future space programs will be multinational.

### World Goals

In the premise, we proposed that the civil space program be oriented in a direction to help solve present and future world problems and also help ensure a long-term continuous effort as presented in Table 10.

Here we propose that space scenarios be developed that utilize technologies indigenous to future world problems. The author had twin sons in college who associate with students from other nations, all of whom are studying in the U.S.A. prior to returning to their home countries after graduation. Upon query, these young people agreed on a list of problems they feel the world will be concerned with in the next 50 years. There was no total agreement regarding sequence, but they agreed on overall content. The listing follows in Table 11.

As we briefly discussed in the premise, there are many problem areas. Rather than attempt to cover all of them, we have selected a specific subset for this presentation. Goals can be set that will affect the technology push for humans in space and will, in turn, influence possible scenarios.

Table 10. Approach toward maximum world benefit from human space technology

|   |   |
|---|---|
| <ul style="list-style-type: none"> <li>Previous scenarios have generally minimized cost within the scope of certain groundrules such as</li> </ul>  | <ul style="list-style-type: none"> <li>Return to lunar surface first to stay</li> <li>Mars mission follows</li> <li>Advance space technology</li> </ul>   |
| <ul style="list-style-type: none"> <li>Development dollars and technology push tends to focus on minimizing mass in LEO and following previously chartered paths beyond current boundaries</li> </ul> |   |
| <ul style="list-style-type: none"> <li>New scenario groundrules, in order of priority</li> </ul>  | <ul style="list-style-type: none"> <li>Development dollars focused first on agreed-upon technologies most likely to feedback into civilian economy</li> <li>Development dollars focused second on agreed-upon scientific goals and objectives of national and worldwide importance</li> </ul> |
|   | <ul style="list-style-type: none"> <li>Program distribution to bring in all interested and capable parties</li> <li>Program is designed to break into clean interface parts that can be split among parties without massive management overhead</li> </ul>                                    |

H1306, Table 10, 1/28/93, 04:31 PM

Table 11. College students' list of national and worldwide problems

|   |  |
|---|--|
| <ul style="list-style-type: none"> <li>Energy cost</li> <li>Hunger</li> <li>Pollution control</li> <li>Climate vagaries</li> <li>Poverty</li> <li>Literacy</li> <li>Health maintenance</li> </ul> | <ul style="list-style-type: none"> <li>Nationalism</li> <li>Taxes</li> <li>Jobs</li> <li>Atmosphere control</li> <li>Crime</li> <li>Motivation of the young</li> </ul> |
|---|--|

H1306, Table 11, 1/28/93, 04:31 PM

This short set of goals is displayed in Table 12 and is the subject of the remainder of our paper.

Table 12. World goals approach

| Concern   | Strategy  | Architecture effect  |
|---|---|--|
| <ul style="list-style-type: none"> <li>Low-cost, nonpolluting energy</li> </ul>         | <ul style="list-style-type: none"> <li>Utilize DOE to pursue power and propulsion</li> </ul>              | <ul style="list-style-type: none"> <li>Fusion for Mars; solar or electric prop; lunar solar elec power; potential He3 mining and fusion power</li> </ul> |
| <ul style="list-style-type: none"> <li>Low water, low pesticide plant growth</li> </ul> | <ul style="list-style-type: none"> <li>Emphasize bioregenerative ecological system development</li> </ul> | <ul style="list-style-type: none"> <li>Push plant growth solutions in SSF and Moon for Mars</li> </ul>   |
| <ul style="list-style-type: none"> <li>Pollution waste and water control</li> </ul>     | <ul style="list-style-type: none"> <li>Closed-cycle ECLSS development first on SSF/Moon</li> </ul>        | <ul style="list-style-type: none"> <li>Water and waste management recycling system</li> </ul>  |
| <ul style="list-style-type: none"> <li>AIDS or aging</li> </ul>                         | <ul style="list-style-type: none"> <li>Emphasize immune system breakdown research</li> </ul>              | <ul style="list-style-type: none"> <li>Early experiments on SSF and the Moon prior to Mars</li> </ul>  |

H1306, Table 12, 1/28/93, 04:31 PM

### Low-Cost, Nonpolluting Energy

The world population has finally recognized that we are polluting our nest. We are also using energy at a prodigious rate (Figure 3). There is a demonstrated connection between the cost of energy, its availability, and a nation's standard of living. Long-term clean energy sources must be researched to provide for our own future needs as well as for other nations. Energy sources are an important part of environmental thrusts. Nuclear research is progressing but does not promise near-term solutions and the developed nations are reaching a plateau of available power. The emerging nations need power but environmental damage caused by fossil fuel burning is greater than the nuclear energy risks. Currently the U.S. annually consumes about 2.8 trillion Kwh's of electrical energy, and if this rate grows at only 2% per year, by 2050 U.S. power requirements will be around 9 trillion Kwh's. Total world needs, assuming a very low use by developing nations, easily exceeds an estimated 20 trillion Kwh's by the 2050 time period. Even with the attendant tripling of nonnuclear systems, such as hydroelectric power to avoid fossil fuel system proliferation, nuclear power system usage

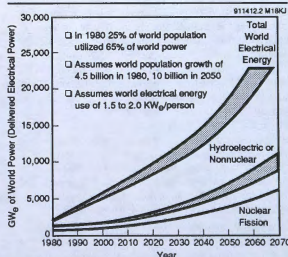


Figure 3. World power needs—electrical power generation



would have to increase by a factor of 6 to meet requirements. This later in the face of a rising discontent with the environmental effects of current nuclear energy waste disposal, and some plants are being converted to use fossil fuels rather than nuclear energy. A clean, renewable source of energy must be found and implemented. Space can hold solutions to this problem if we are politically and economically willing to reach for them. Three potential clean and renewable energy sources are described in Table 13.

**Table 13. Space-based energy sources**

|                                     |   |
|-------------------------------------|---|
| Helium-3 system concept             | <ul style="list-style-type: none"> <li>Helium-3 is mined on lunar surface and transported to Earth for use in fusion reactors</li> <li>Deuterium and He-3 fuses cleanly and produces little radiation and waste</li> <li>We estimate that enough He-3 is on lunar surface to satisfy current world energy needs for 1000 years</li> </ul> |
| Solar Power Satellite (SPS) concept | <ul style="list-style-type: none"> <li>Many satellites in geosynchronous Earth orbit transmitting solar energy via microwave to the surface</li> <li>5000 mW of electric power per satellite</li> <li>Use lunar materials for construction of SPS and transportation system to place in geosynchronous orbit</li> </ul>                   |
| Lunar Power System (LPS) concept    | <ul style="list-style-type: none"> <li>LPS will collect solar energy on lunar surface and transmit back to Earth via microwave</li> <li>LPS used first to power lunar base to demonstrate technology</li> <li>Mirrors in orbit will supply base with solar energy during lunar night</li> </ul>   |

H1306, Table 13, 1/28/93, 04:31 PM

Helium 3, Solar Power Satellites (SPS), and a Lunar Power System (LPS) all have significant feedback potential for other commercial applications besides providing an unlimited clean energy source. A space-based energy system will be global in scale and funding, and will be a challenging goal for macroengineering management to achieve. The management experience will be globally shared and utilized for other large projects. Robotics and artificial intelligence will also benefit the implementation of a space-based energy system; smart and capable robots will autonomously perform such functions as lunar mining and processing. Computer systems will be extended in capability and reliability, and energy transfer technology will be amplified. Materials research will be stimulated by the desire to utilize in situ materials. SPS and LPS will require advancement to photovoltaic cell technology. This will also influence SEI scenarios since at least one of the solutions leads directly to production of high performance, low radiation fusion propulsion systems. Such systems promise much shorter Mars trip times to possibly facilitate extensive artificial gravity and galactic radiation protection solutions that may be needed for year-long journeys.

These three potential energy solutions are the subject of a NASA technical memorandum (TM). This report, TM 101652, discusses the Solar Power Satellite, the Lunar Power System, and a potential Helium 3 endeavor.

#### **Low Water, Low Pesticide Plant Growth, Waste, and Water Purity Control**

Two items listed here represent major concerns of most developed nations and are emerging concerns in developing nations. A technological revolution is needed to address

food shortages to feed our exploding world population in concert with ever-growing water shortages, and a growing realization that our current pesticide methods are radically polluting the planet. Our fast-disappearing garbage dump areas and the problems of water control and reuse have spawned whole new industries in the last few years.

While previous short-duration manned space programs have depended on open-loop life support systems, future human space effort cannot. In their 90-Day Report and many subsequent studies, NASA has identified an evolutionary life support system path through the partial regenerative Space Station Freedom (SSF) approach that will recycle only oxygen and water and depend on logistics resupply for other consumables, spares, and waste management. The path then continues on through progressive development of a closed-cycle physical chemical extension of the SSF approach finally culminating in a bioregenerative system. We realize, as does any good system engineer, that the reduced resupply requirements must be traded off against system cost, power requirements, volume, reliability, maintainability, and limitations of other resources; however, reaching for the Controlled Ecological Life Support System (CELSS) may well lead to world benefits far beyond a lesser approach.

Areas of emphasis in the CELSS approach are mentioned in Table 14. Many long-term (and pressing short-term) world problems can be approached by reaching for the stars. Shimizu Corporation, a member of the McDonnell Douglas group, is most interested in bioregenerative systems for one predominant reason-to find a potential solution for Tokyo's waste management problems.

**Table 14. Critical CELSS development areas**

|  |   |
|--|---|
| Plant growth in controlled environment | <ul style="list-style-type: none"> <li>Select crop plants for nutritional value and productivity</li> <li>Optimize and control plant growth response</li> <li>Develop support systems to allow growth in closed chambers</li> </ul>   |
| Waste processing and nutrient recovery | <ul style="list-style-type: none"> <li>Develop energy-efficient waste processor to convert plant and human waste into plant nutrients and water</li> <li>Develop biomass processor to convert some portion of inedible plant materials into dietary supplements</li> </ul>  |
| Atmosphere revitalization              | <ul style="list-style-type: none"> <li>Develop technology for makeup nitrogen generation</li> <li>Remove CO<sub>2</sub> reduction by-products</li> <li>Improve trace contaminant control and monitor</li> </ul>   |
| Plant growth in reduced or micro-g     | <ul style="list-style-type: none"> <li>Study crop plant productivity with microgravity as worst case</li> <li>Determine ability of support systems to function in microgravity</li> <li>Perform multiple-generation studies in space radiation low-g environment</li> </ul> |
| Plant growth in controlled environment | <ul style="list-style-type: none"> <li>Develop laboratory system to investigate microbial interactions and toxicology</li> <li>Determine control strategies to provide stable life support system</li> </ul>  |
| Water management                       | <ul style="list-style-type: none"> <li>Eliminate using pretest chemicals</li> <li>Regenerate or eliminate post-treatment filter and sorbent beds</li> <li>Improve quality monitoring</li> </ul>   |

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#### **Human Physiology, Aging, and AIDS**

Many current human problems are the result of changes or failures of the body's natural immune system. We can diagnose many of these effects, and have made great strides



in ameliorating the symptoms, but to date immune system function has defied understanding.

Both U.S. (84-day) and Soviet (300-day) missions have evoked similar red blood cell and immune system changes. Hematological and immunological changes observed during, or after, space missions have become quite consistent. Decreases in red blood cell mass were reported in Gemini, Apollo, Skylab, and Soyuz programs probably due to diminished rates of erythrocyte production. Space flight at micro-g levels may involve changes in white blood cell morphology and a compromise of the immune system. Skylab studies indicated a decrease in the number of T lymphocytes and some impairment of their function. Some U.S. and Soviet findings suggest that space flight induces a transient impairment in immune system function at the cellular level. Some data from year-long Soviet missions suggest a complete breakdown of the immune system is possible. However, these changes disappeared postflight within 3-4 weeks.

Space flight offers a clinical laboratory unlike any place on Earth to understand the function of the human immune system. Perhaps cures for aging, AIDS, and other immune function-related illnesses can result from proper use of the space laboratory and investigation into the long-term human reaction to space. One other physiology effect may affect both space travel and earthbound people. Several ideas promulgated during the recent outreach endeavor have drawn comparisons between hibernating animals and space flight effects. For instance, bears appear to utilize physiological mechanism pathways to prevent calcium loss from bones into urine and feces, and lean body mass loss as reflected by nitrogen in urine. A new chemical isolation technique has isolated unique substances associated with these pathways. These same substances may prevent loss of human bone calcium and lean body tissue while at low-g conditions. This research may have potential for treating osteoporosis, kidney disease, and burns and trauma in humans.

Space is a laboratory from which we may well develop synergistic cures for many of man's illnesses as byproducts of our eventual manned trip to Mars.

#### Scenario Comparisons

Table 15 presents three potential scenarios that could describe future human space flight. If one compares the first two scenarios to the third "maximum back (maxback)" approach, which attempts to maximize feedback to jobs, education, economics, and future world goals, some interesting comparisons can be made (Table 16). The maxback approach, which is specifically designed to develop technologies with the greatest feedback potential, is worth closer investigation. The role of human space flight in solution of worldwide problems is summarized in Table 17.

#### Summary

From our analysis a series of conclusions and recommendations can be made and are listed in sequence.

Table 15. Human space flight approaches

|                         |  |
|-------------------------|--|
| 1. Flags and footprints | <ul style="list-style-type: none"> <li>Land humans on Mars and return safely</li> <li>Apollo-type mission</li> <li>Few (about 3) human missions to Mars for 30 days with limited scientific observations and surface analysis</li> <li>Utilize available technology where possible - only minimum new thrusts</li> <li>Discontinue effort after human landings</li> <li>Precede human landings with robotic missions</li> </ul>  |
| 2. Minimum approach     | <ul style="list-style-type: none"> <li>Utilize Moon and SSF as test-beds for human Mars mission</li> <li>Utilize Moon to demonstrate habitats, rovers, life sciences, and operations</li> <li>Lunar stay times of 30-90 days in human-tended emplacements</li> <li>Utilize common transfer vehicles and surface equipment for lunar and Mars missions</li> <li>Stay-time on Martian surface of 30-90 days with about 8 months in Mars orbit</li> <li>Limit development on in situ or closed-cycle systems</li> <li>Precede human landings with robotic missions</li> </ul> |
| 3. Maxback              | <ul style="list-style-type: none"> <li>Utilize Moon and SSF as test-bed for Mars, but design for eventual permanent lunar and Mars emplacements</li> <li>Utilize in situ resources for construction, propulsion, life support</li> <li>Implement closed-loop and CELSS - 100% self sufficiency</li> <li>Utilize artificial gravity in transfer systems</li> <li>Develop in situ lunar and Mars power systems</li> <li>Utilize robotics extensively for probes, sample return, site identification, and surface operation</li> </ul>  |

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#### Conclusions

- To become more competitive internationally, the U.S. needs high technology developments to strengthen its industries.
- Technology developments spurred by NASA and other government agencies are a main reason for the U.S. aerospace industry's dominance in international trade.
- As an investment in the American economy, space program funding creates thousands of jobs and billions of dollars of value both directly and indirectly.
- To date, space technology applications have had reasonable spin-off potential; however, most technologies were single-purpose oriented and not part of an overall feedback plan.
- As seen during the Apollo program, the space program has a direct effect on motivating students to seek advanced technical degrees.
- The number of students seeking engineering and science degrees has decreased steadily leading to shortages in all U.S. industries.
- By utilizing government facilities, contractors, and universities, space research programs can be distributed to many areas of the country.
- Previous space technology developments have contributed significantly to the U.S. standard of living.
- Many space technologies can alleviate some of the world's most pressing problems.
- A clean, renewable source of global energy may determine our environmental fate as well as provide for our ever-increasing energy needs.
- More demanding and ambitious exploration scenarios require more research and technology development and, therefore, have more potential for valuable feedback.
- Many areas of space R&D can have significant feedback potential.

Table 16. Space exploration options comparison

| Research area               | Option |    |    | Comments  |
|-----------------------------|--------|----|----|---|
|                             | 1      | 2  | 3  |   |
| Artificial gravity          | 4      | 3  | 1  | Serious research of this nature will only be for programs seeking its use. Maxback will force this research; minimum approach may require limited studies.      |
| Small nuclear power systems | 3      | 3  | 1  | All options may utilize some type of RTS, but maxback will require SP-100 Class nuclear reactors  |
| Artificial intelligence     | 3      | 2  | 1  | All options will need a measure of artificial intelligence with dependence increasing as mission demands increase   |
| Robotics and teleoperation  | 3      | 2  | 1  | Again, all options will need advances in this technology, but maxback relies most heavily on robotics for base construction and surface operations              |
| Life sciences               | 2      | 1  | 1  | Significant advances must be made before any trip to Mars or long duration exposure to varying g levels, radiation, etc., is attempted                          |
| Computer systems            | 3      | 2  | 1  | Highest computer demands are for options that rely most heavily on robotics and automation for autonomous operations  |
| 1 atm space suit            | 2      | 1  | 2  | All options will benefit from a 1 atm EMU, with minimum approach needing it most; maxback seeks to reduce EVA time by using robotics and teleoperations instead |
| Macroengineering            | 3      | 2  | 1  | Maxback is a definite macroengineering management challenge because it is the most involved and seeks to utilize many players                                   |
| Mechanical systems          | 2      | 1  | 1  | Improvements in the efficiency and reliability of systems is required for all options   |
| CELSS                       | 4      | 3  | 1  | Ability to produce food is key to becoming self-sufficient. Minimum approach may have limited need for CELSS, but maxback requires the capability               |
| ECLSS                       | 2      | 2  | 1  | Monitor and control of life support systems will be imperative for each option, with the highest demands for maxback  |
| Alternate power sources     | 4      | 4  | 2  | Only maxback has long-term goal of determining construction methods for potential space-based power systems   |
| Materials processing        | 4      | 3  | 1  | Again, only maxback utilizes in-situ resources for propulsion, life support, construction, and other tasks, as a mission requirement                            |
| Totals                      | 39     | 29 | 15 |   |

Legend: Technology development required: Extensive = 1

Moderate = 2 Little = 3 None = 4

Summary: The "rags and footprints" option requires little new technology and will not significantly benefit the taxpayers outside the aerospace community. The minimum approach scenario is better, but maxback is specifically designed to develop technologies with the greatest economic feedback potential.

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Table 17. The role of Space in addressing national and worldwide problems

- Technological advances resulting from space activities can positively affect world needs if programs are designed with this in mind.
- The general public must be informed as to how space-related activities benefit them in the past, present, and future.
- One of the best ways to gather political support for a particular program in a certain area is to direct attention to the resolution of community needs (i.e., stressing jobs created in areas suffering from high unemployment).
- There is a direct relation between space program success and nationalistic pride.
- Space planning must be open-minded to ideas of all participants, domestic and international.

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## Recommendations

- Space research dollars should focus on developing technologies with greatest positive feedback potential.
- Exploration programs should be long-term with built-in evolutionary growth to enable continuing research.
- Near- and long-term goals must be clearly defined before an initiative enters the research phase.
- Keep the general public's interest high during the course

of space exploration to help garner political support. Short-term achievements such as rovers and sample return missions to Mars, the Moon, and the outer planets can create this interest.

- Motivate young people to achieve engineering and science degrees with near- and long-term goals by stressing the role they can play in the space program now and throughout their careers.

- Educate the general public about how the space program benefits them in terms of jobs, money, education, new and better products, and other benefits. Compare how much space exploration costs in comparison to other government programs.

- An exploration program focused on value return to taxpayers is also one committed to having a permanent manned presence in space with continuing solar system exploration. Future space programs provide an opportunity to explore our solar system and better the world for ourselves and future generations.

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